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Specification and Drawings, as originally filed, with Application for Patent Serial No: **2,416,171**, on January 13, 2003, by **PURE TECHNOLOGIES LTD.**, assignee of Peter O. Paulson, for "Pipeline Monitoring System".

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ABSTRACT OF THE DISCLOSURE

Pipeline Monitoring System

An above-ground pipeline is monitored for leaks by a thermal sensor which senses temperature along its length. The sensor is for example a distributed fibre optic sensor or a satellite with an infrared sensor. If a temperature is registered which is higher by a predetermined amount than the ambient temperature, a leak is suspected. This is particularly useful for oil pipelines containing warm oil which pass through arctic or antarctic terrain.

In another embodiment, a pipeline is monitored by a thermal sensor and is also monitored by a acoustic sensor distributed acoustic sensor (such as a fibre optic sensor) or an array of discrete acoustic sensors. When an acoustic event that is similar to the acoustic event made by a collision with the pipeline or fluid escaping from the pipeline is detected, and a thermal anomaly is detected at the same location and approximately the same time, a leak is suspected.

PIPELINE MONITORING SYSTEM

Field of the Invention

The present invention relates to pipeline monitoring systems and in particular to systems for detection of leaks in a pipeline.

Background to the Invention

The present invention provides a monitoring system for pipelines and provides for detection of pipeline leaks, such as those caused by impact to the pipeline or by ageing of the pipeline, resulting in the fluid in the pipeline escaping from the pipeline to the surrounding environment.

Generally pipelines that carry fluids are buried underground and leaks that may occur can go undetected for extended periods of time. More recently, surface deployed pipelines have been installed to transport fluids such as oil from northern areas of the globe. Surface deployed pipelines are subject to environmental exposure including wind, rain, sunlight and collision with man-made objects such as snowmobiles, trucks, falling rocks and the like. When a leak occurs in an environmentally sensitive area such as in a arctic wilderness area, the escape of the oil fluid can cause considerable loss of a valuable economic resource and environmental contamination.

In the past, it has been proposed to monitor pipelines for leaks using acoustic apparatus such as for example, in Canadian patent no. 2,066,578 using a plurality of acoustic sensors. It is possible to use acoustic sensors to hear noises (known as "acoustic events") and it is possible to determine the location at which the acoustic event has occurred. However, it is much more difficult to determine the meaning of

the acoustic events, and whether they relate to a leak. When a pipeline runs above ground, acoustic sensors are particularly likely to give false positive readings due to the surrounding environmental conditions.. For example, wind, rain, lightning, and other naturally occurring effects can produce acoustic events that may appear to indicate that a leak or collision with the pipeline has occurred, when in fact such a collision or leak has not occurred.

Summary of the Invention

The present invention provides a system for monitoring of pipelines that is particularly well suited to the monitoring of above ground pipelines for leaks and the like.

In one broad aspect of the invention, a continuous distributed acoustic sensor or sensors spaced along or in close proximity to the pipeline to be monitored are provided. In addition, temperature sensors or a continuous distributed temperature sensor are deployed along or in close proximity to the pipeline. In a preferred embodiment, the temperature sensors are a distributed fibre optic thermal sensor capable of sensing temperature along the entire length of the pipeline or along a desired pipeline segment. In a further preferred embodiment, the acoustic sensor is a continuous distributed fibre optic acoustic sensor capable of sensing acoustic events at any point along the pipeline or a desired segment of the pipeline, .In a particularly preferred embodiment, the acoustic sensing is done by a distributed acoustic sensor and the temperature sensing is doe by a distributed thermal sensor. In such a case, the acoustic and thermal sensors can use the same optical fibre or can use different optical fibres.

The output of the acoustic monitoring is compared with normal background for anomalies and the presence of an acoustic anomaly is selected as an event of interest. The output of the thermal sensor is monitored for anomalies, and the presence of a thermal anomaly is selected an event of interest. When events of

interest are found using the two sensors at the same location and approximately at the same time, a leak is suspected. The appearance of a leak will generate spatially and temporally coincident acoustic and thermal anomalies. The recognition of the coincidence of these anomalies allows the rejection of false alarms from sources other than leaks, which could lead to anomalies in either acoustic events or temperature changes, but is not likely to lead to both.

In a second broad aspect of the invention, a distributed thermal sensor or a temperature sensor or sensors are placed exterior to the pipeline to measure temperature along substantially the whole length of pipeline to be monitored. Acoustic sensors need not be present, although they can be. This embodiment is used in conjunction with an above-ground pipeline, particularly in an environment where the contents of the pipeline are at a significantly different temperature from the ambient temperature. If there is a leak, the contents of the pipeline change the temperature monitored, and indicate the presence of the leak.

Description of the Invention

According to one aspect of the invention, a pipeline to be monitored is configured with at least one distributed acoustic sensor, or with a plurality of conventional acoustic sensors a located on or in close proximity to the pipeline. The acoustic emissions generated within the pipeline such as emissions produced when a pipeline undergoes an event such as an impact or collision with an object or a perforation failure in a high-pressure pipe produces an acoustic event of interest. As an example, each of the sensors in the plurality of acoustic sensors can be a The preferred type of sensor is a fibre optic interferometric acoustic sensor deployed continuously along the pipeline or near to the pipeline. One suitable type of sensor is available from The distributed Acoustic sensor is available from Optiphase, Inc.,7652 Haskell Ave. Van Nuys, CA 91406, USA. The sensor can be placed in along the exterior insulating jacket of the pipeline or affixed to the exterior of the pipe itself. Each of the sensors placed along the pipeline provides a monitoring for acoustic

signals in the region of the pipeline over which the sensor is sensitive. When acoustic signals representative of an event occurs, the output from the sensor will show a variation corresponding to the acoustic event.

As a less preferred alternative, piezoelectric acoustic sensors can be mounted on or in the pipeline, as shown in Canadian Patent 2,066,578, or can be mounted in arrays in the pipeline, as shown in US Patent 6,082,193, or such sensors or microphones can be mounted in arrays along the outside of the pipeline.

The preferred temperature sensor is a fiber optic distributed thermal sensor deployed continuously along or in close proximity to a pipeline. A suitable sensor can be obtained from Sensa, Gamma House, Enterprise Road, Chilworth Science Park, Southampton SO16 7NS, England. Variations in the detected light received allow continuous assessment of the temperature of the fiber along its length.

Simultaneous occurrence of an acoustic event and a thermal event are indicative of an event of interest such as a leak in the pipeline.

When a pipeline is located above the surface of the ground, it is exposed to environmental factors including wind, rain, lightening and hail. These environmental factors can produce acoustic outputs or thermal outputs that are similar to outputs produced when a leak of the fluid from the pipeline occurs. However, because there are a plurality of acoustic sensors spaced over the length of the pipeline being monitored, an environmental factor such as rain or wind will occur along a substantial portion of the pipeline under test. Thus a plurality of the acoustic sensors will to respond to the environmental effects caused by rain, wind or hail. Consequently, an environmental factor can be discounted as a source of pipeline leak because the effect of the environmental factor will be monitored by a plurality of the sensors. On the other hand, a localized leakage phenomenon will produce a

variation in output or event of interest in a localized segment of the pipeline in the area of the leak.

In the fibre optic thermal detection system, a fibre optic cable has a light source to supply light to the optical fiber and a light detector to detect light from the optical fiber. Environmental changes will produce effects at various locations along the fibre, but a leak will only produce changes in the region of the leak. However, when the pipeline is subjected to environmental factors, such as for example rain, the effect of the rain will extend over a substantial portion of the pipeline. Consequently, the temperature varying effect of the rain will manifest itself over a large length of pipe relative to the length that would be impacted in the event that a pipeline leak occurs. With a pipeline leak, the fluid egress from the pipeline is localized to a section of the pipe that is vastly smaller than the section of the pipe than would be affected by an environmental factor such as rain. Consequently, the both the thermal and acoustic effects manifested when a leak occurs are localized phenomena.

Where the portion of the pipeline to be monitored is completely above ground and visible form above, another preferred form of temperature sensing is by satellite.

In another embodiment, used preferably where the ambient temperature is more than about 10-15 degrees Celsius below the temperature of the pipeline, the acoustic sensor is not used, and only temperature sensing is done. Temperature readings that indicate a hot location are then investigated as possible leaks This embodiment is particularly suitable for use with oil pipelines passing above ground in arctic or Antarctic regions, where the oil temperature is quite different from, and higher than, the ambient temperature.. It is useful to calculate the expected oil temperature at each location along the pipeline, and compare such temperature with the temperature of any hot patch, as a further verification of whether the hot patch is likely to have been caused by an oil leak.

Brief Description of the Drawings

The preferred embodiments of the invention will now be described in detail with reference to the following drawings in which:

Figure 1 is an elevation view of a portion of a pipeline configured with an embodiment of monitoring apparatus in accordance with the invention.

Figure 2 is an elevation view of a portion of a pipeline configured with a second embodiment of monitoring apparatus in accordance with the invention.

Detailed Description of the Preferred Embodiment

Figure 1 shows an elevation view of a portion of a pipeline 10 which is disposed above the surface of the ground and supported on a plurality of pedestals 12 as it traverses the terrain over which the pipeline is deployed. A distributed acoustic sensor 14 is shown extending along the length of one segment pipeline 10. In the embodiment of Figure 1, acoustic sensor 14 is disposed along one segment of the pipeline to respond to acoustic events in the pipe segment to which it is affixed. The pipeline 10 takes a zigzag configuration as is customary in above ground pipeline construction to enable the pipeline to maintain integrity with the expansion and contraction that will occur through seasonal heating and cooling of the pipeline along its length over the course of the year. Naturally, when pipeline 10 is buried below ground, the more customary configuration of the pipeline structure is a substantially linear configuration along the distance over which it extends.

A distributed thermal sensor 16 is shown extending along the length of pipeline that the fibre optic link is intended to monitor. Both sensor types will extend for a distance of several pipeline segments and can run to several kilometres during the course of the pipeline length. The fibre optic sensors are shown disposed along the exterior of the pipeline in a generally axial direction. It is not necessary for the fibre

optic sensor to be wrapped helically about the pipeline as any fluid leaks which will occur will have a tendency to drain along the exterior of the pipeline and, consequently, come into contact with the fibre optic sensor when the sensor is positioned along the lower portion of the pipeline. Therefore, it is preferable that the fibre optic sensor be placed along the lower or bottom portion of the pipe to facilitate contact of the fibre optic sensor with fluid being expelled from the pipe from a leak that may occur in the pipe on either side of the pipe.

In the embodiment shown, one segment A of the pipeline is monitored by both acoustic sensor 14 and thermal sensor 16. The other segment B is monitored only by a thermal sensor. Suitable cabling 18 and microprocessor 20 are shown diagrammatically to receive and process the output signals of the sensors.

If desired, two thermal distributed fibre optic sensors are provided, one on each side of the pipeline to facilitate response to a leak occurring on either side of the pipeline. However, usually one thermal fibre optic sensor sensor, located near the bottom of the pipeline, is sufficient. While a highly pressurized pipeline will expel the fluid transported in the pipe outwardly and away from the pipeline, a portion of the fluid escaping from the pipe will adhere to the surface and run along the exterior circumference of the pipeline to come in contact with the fibre optic sensor near the bottom of the pipeline.

Figure 2 shows an alternate embodiment. The same numbers are used for like elements. In figure 2, the thermal sensor is a satellite 100, positioned to survey the segments A and B with an infra-red sensing device. It sends the information sensed to the microprocessor 20 signals by as suitable communications link 101. The acoustic sensors are an array of microphones 110 mounted on the surface of part of segment A and an array 111 of piezoelectric sensors in the interior of the pipeline to be present in the fluid flow which is transported within the pipe. These are connected with the microprocessor by cables 120 and 121 respectively. into a signal representative on the measurements. Therefore, the optical interface circuit shown

generally in Figure 1 relates to both the creation and detection of optical signalling in the fibre optic detectors and conversion of those optical signals into electrical signalling suitable for use in microprocessor 20. The communication between the optical interface circuit 18 and the microprocessor 20 is via an interface cable 22 which may be any suitable input/output signalling as is Microprocessor 20 performs monitoring of the optical thermal and acoustic sensor data and produces an event log 26.

Figure 2 shows one arrangement to utilise a fibre optic as a distributed acoustic sensor. Many arrangements are possible and are commercially available.

What is claimed is:

1. A process for locating a leak in a pipeline, which comprises:

(a) continuously sensing acoustic events which occur relative to the pipeline and their location along the pipeline at which they occur

(b) continuously sensing the temperature along the pipeline exterior to the pipeline adjacent to the exterior of the pipeline

(c) determining when there is an acoustic event at a location along the pipeline, and a substantially contemporaneous change in temperature adjacent to the exterior of the pipeline at that location.

2. A process as claimed in claim 1, in which the sensing of the temperature along the pipeline is carried out with sensing apparatus oriented so that fluid escaping from the pipeline is likely to contact it.

3. A process as claimed in claim 1 or claim 2 in which the sensing of acoustic events is carried out by a distributed fibre optic acoustic sensor.

4. A process as claimed in claim 1 or claim 2 in which the sensing of temperature is carried out by a distributed fibre optic temperature sensor.

5. A process as claimed in any of claims 1-4 in which the pipeline is at least partially above ground.

6. Apparatus for sensing leaks in a pipeline, which comprises:

(i) acoustic sensing means for detecting acoustic events occurring along the pipeline, and the location of such events:

(ii) temperature sensing means for determining temperature along the exterior of the pipeline;

(iii) means for collating the output of such acoustic sensing means and said temperature sensing means to determine situations where there is an acoustic event, with a substantially contemporaneous temperature change occurring at the same location.

7. Apparatus as claimed in claim 6, in which said temperature sensing means is a distributed fibre optic temperature sensor.

8. Apparatus as claimed in claim 7, in which the distributed fibre optic temperature sensor is below the pipeline and substantially adjacent to it, whereby liquid leaking from the pipeline is likely to impinge on such sensor.

9. A process as claimed in any of claims 6-8, in which the acoustic sensing means is a distributed fibre optic acoustic sensor.

10. A process as claimed in any of claims 6-9 in which the pipeline is at least partially above ground.

11. A process as claimed in claim 6, in which the pipeline is substantially above ground and visible from above, and the temperature sensing means is a satellite-mounted temperature sensor.

12. A process for locating a leak in a pipeline, which comprises:

(a) continuously sensing the temperature along the pipeline exterior to the pipeline adjacent to the exterior of the pipeline

(c) determining that there is a probable leak when the temperature in a particular location along the pipeline is greater by at least a predetermined amount than the temperature at other locations along the pipeline.

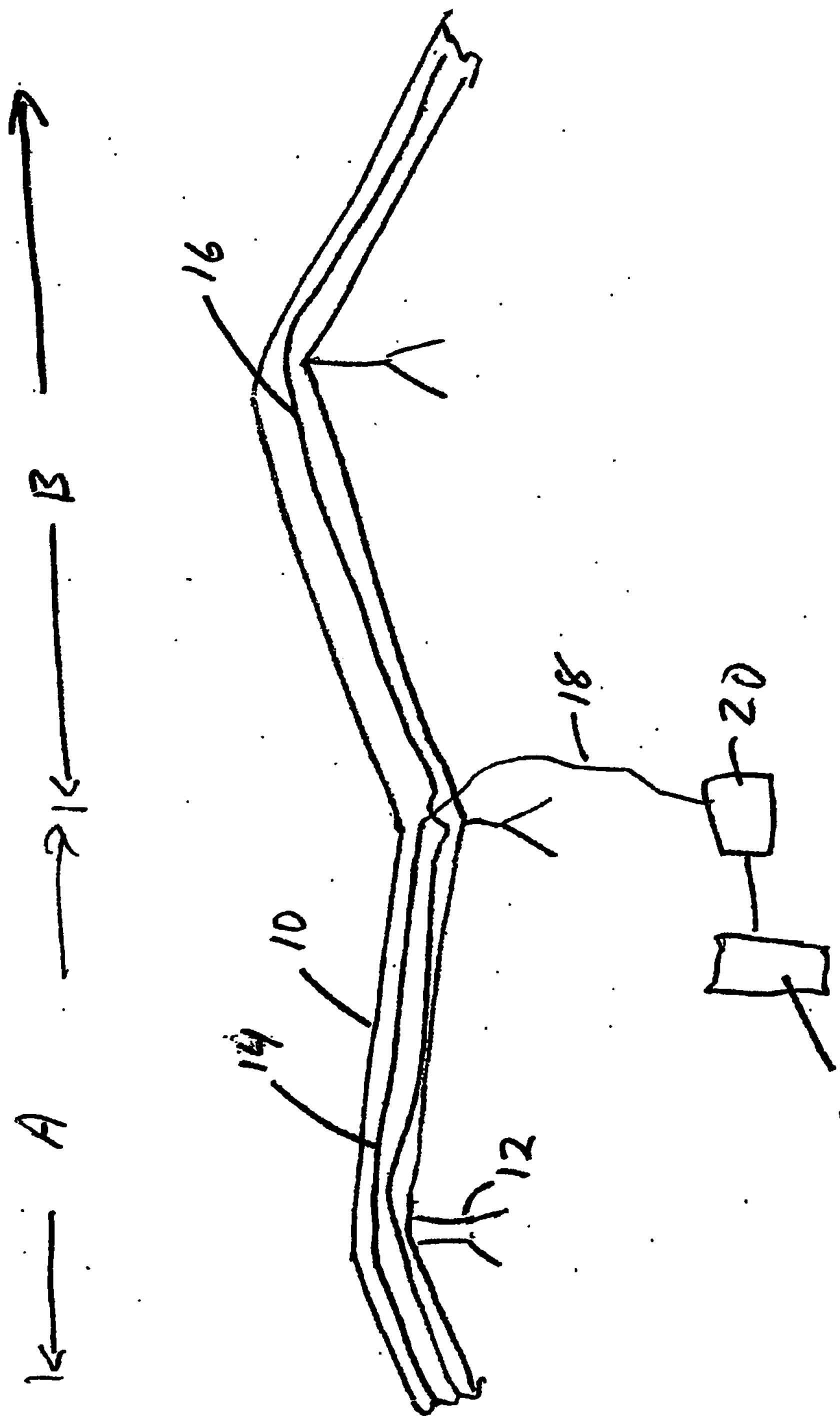

Figure 1

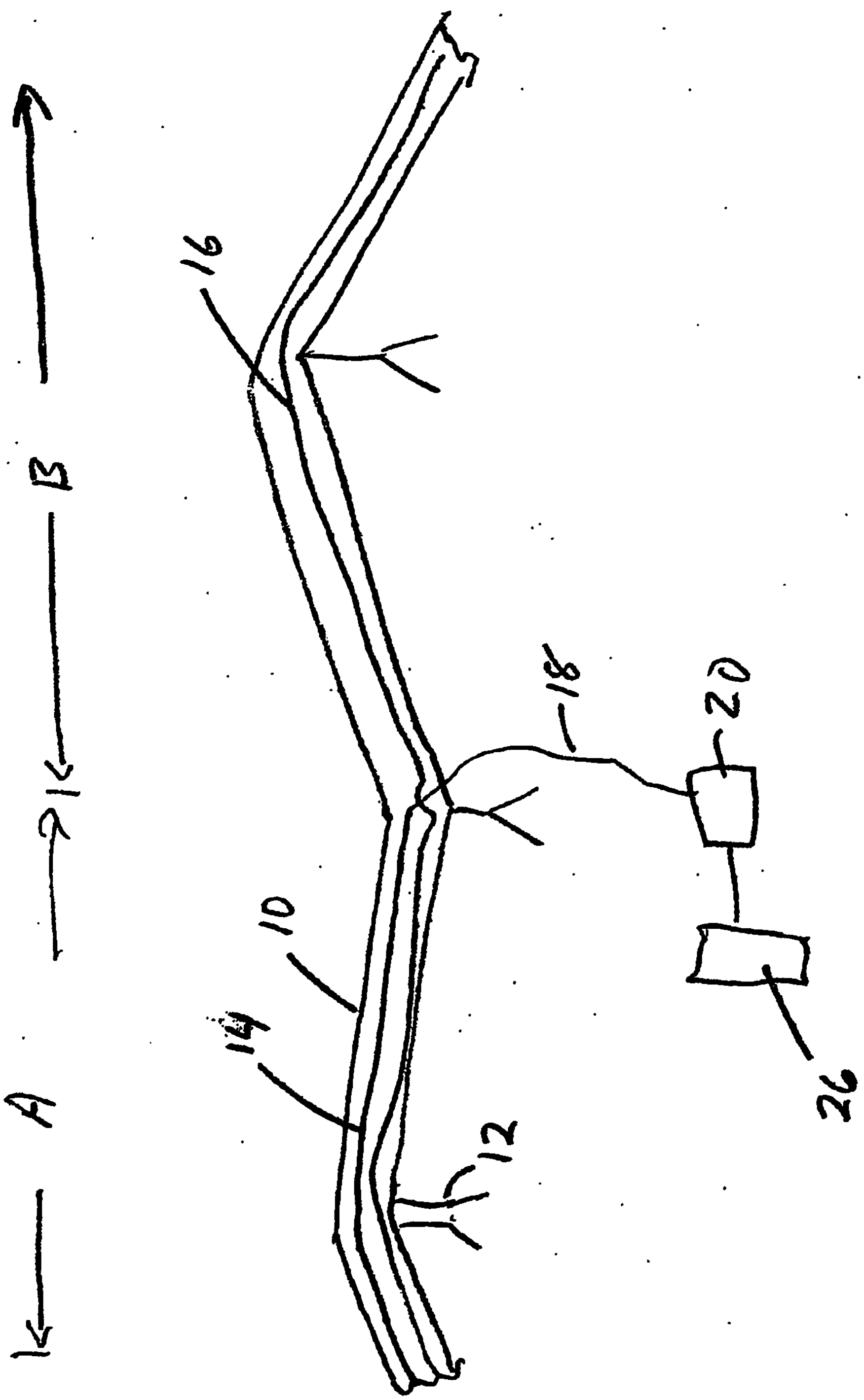

Figure 1